GP-303407

BRAKE BOOSTER VACUUM PREDICTION ALGORITHM AND METHOD OF USE THEREFOR

TECHNICAL FIELD

[0001]   The present invention relates to motor vehicles and, more particularly, to motor vehicles with brake boosters using vacuum for brake pedal assist.

BACKGROUND OF THE INVENTION

[0002]   Most engines on motor vehicles with brake boosters using vacuum (brake booster vacuum) for brake pedal assist utilize the engine intake manifold as a vacuum source for the brake booster to provide sufficient brake booster vacuum to meet vehicle braking requirements.

[0003]   Some engines now use Displacement on Demand, which deactivates cylinders when load requirements are low, and/or use variable valve timing and/or other engine controls that can affect brake booster vacuum. These technologies improve fuel economy by reducing intake manifold vacuum (that is, the absolute pressure of the intake manifold increases) in order to reduce pumping losses. When the reduced intake manifold vacuum is such that the brake booster vacuum exceeds a calibrated brake booster vacuum threshold (that is the absolute pressure of the brake booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), it could theoretically result in inadequate brake booster vacuum to meet vehicle braking requirements and engine operation must be modified to provide adequate intake manifold vacuum to meet brake booster vacuum requirements for vehicle braking. For example, on engines with Displacement on Demand, the engine operation is modified to disable cylinder deactivation to increase manifold vacuum, whereas on engines with

variable valve timing, engine operation could be modified to increase intake valve opening to increase manifold vacuum.

[0004]   Presently, a vacuum sensor could be used in the brake booster to determine if the brake booster vacuum exceeds a calibrated brake booster

5   vacuum threshold, whereupon engine operation would be modified to increase manifold vacuum to meet brake booster vacuum requirements for vehicle braking, but at an added cost per vehicle. Another alternative could be a supplemental vacuum pump to assist manifold vacuum to meet brake booster vacuum requirements for vehicle braking, but at an even higher cost

10   per vehicle.

[0005]   Accordingly, what is needed in the art is a less costly alternative to provide adequate intake manifold vacuum to meet brake booster vacuum requirements for vehicle braking by modifying engine operation when the intake manifold vacuum is such that the brake booster

15   vacuum exceeds a calibrated brake booster vacuum threshold.

SUMMARY OF THE INVENTION

[0006]   The present invention is an algorithm residing, preferably, within the main engine controller or engine control module (ECM) of a

20   motor vehicle, which predicts or estimates brake booster vacuum for vehicles using vacuum for brake pedal assist. The predicted or estimated brake booster vacuum is compared to a calibrated brake booster vacuum threshold to determine if adequate brake booster vacuum is available to meet vehicle braking requirements, whereby engine operation can be modified, as

25   necessary, to improve intake manifold vacuum such that brake booster vacuum requirements for vehicle braking are better satisfied.

[0007]   In a first preferred embodiment of the present invention, vehicle input parameters are, at least, manifold absolute pressure (MAP), atmospheric pressure, and vehicle speed, all of which being available from

30   the main engine controller or engine control module (ECM). Vehicle speed

is used to determine vehicle deceleration by which the occurrence of a brake

event can be determined. Changes in brake booster vacuum are modeled

based on the level and duration of the vehicle deceleration and the intake

manifold vacuum using look-up tables containing vehicle specific parameters

5   by which brake booster vacuum is then predicted or estimated. The

predicted or estimated brake booster vacuum is then compared to a calibrated

brake booster vacuum threshold to determine if adequate brake booster

vacuum is available to meet vehicle braking requirements. If not, engine

operation is modified to improve intake manifold vacuum such that brake

10   booster vacuum requirements for vehicle braking are better satisfied.

[0008]   In a second preferred embodiment of the present invention,

vehicle input parameters are, at least, manifold absolute pressure (MAP),

atmospheric pressure, and vehicle speed, all of which being available from

the main engine controller or engine control module (ECM). Vehicle speed

15   is used to determine vehicle deceleration by which the occurrence of a brake

event can be determined. Brake booster vacuum is repeatedly predicted or

estimated through repeated calculations utilizing known and calculated

vehicle parameters and variables, instead of look-up tables containing vehicle

specific parameters as in the first preferred embodiment of the present

20   invention. The calculated prediction or estimation of brake booster vacuum

is compared to a calibrated brake booster vacuum threshold to determine if

adequate brake booster vacuum is available to meet vehicle braking

requirements. If not, engine operation is modified to improve intake

manifold vacuum such that brake booster vacuum requirements for vehicle

25   braking are better satisfied.

[0009]   In a third preferred embodiment of the present invention,

vehicle input parameters are, at least, manifold absolute pressure (MAP),

atmospheric pressure, and brake pedal position, all of which being available

from the main engine controller or engine control module (ECM). Brake

30   pedal position may, for example, be obtained from a variable resistor or

potentiometer attached to the brake pedal, whereby the output resistance is functionally related, for example empirically, to brake pedal position. Brake booster diaphragm position, or equivalently, brake master cylinder displacement as a function of brake pedal position is then, preferably,

5   empirically determined and stored in ECM memory thereby providing a functional relationship between brake pedal position and brake booster diaphragm displacement or brake master cylinder displacement. Brake pedal position is used to determine the occurrence of a brake event. Brake booster vacuum is repeatedly predicted or estimated through repeated calculations

10   utilizing known and calculated vehicle parameters and variables, instead of the look-up tables containing vehicle specific parameters as in the first preferred embodiment of the present invention. The calculated prediction or estimation of brake booster vacuum is compared to a calibrated brake booster vacuum threshold to determine if adequate brake booster vacuum is available

15   to meet vehicle braking requirements. If not, engine operation is modified to improve intake manifold vacuum such that brake booster vacuum requirements for vehicle braking are better satisfied.

[0010]   In a fourth preferred embodiment of the present invention, vehicle input parameters are, at least, manifold absolute pressure (MAP),

20   atmospheric pressure, and brake pedal position, all of which being available from the main engine controller or engine control module (ECM). Brake pedal position may, for example, be obtained as described with respect to the third preferred embodiment. Brake booster diaphragm position, or equivalently, brake master cylinder displacement as a function of brake pedal

25   position is then, preferably, empirically determined and stored in ECM memory, thereby providing a functional relationship between brake pedal position and brake booster diaphragm displacement or brake master cylinder displacement. Brake pedal position is used to determine the occurrence of a brake event. Changes in brake booster vacuum are modeled based on the

30   brake pedal position and the intake manifold vacuum using look-up tables

containing vehicle specific parameters by which brake booster vacuum is then predicted or estimated. The predicted or estimated brake booster vacuum is compared to a calibrated brake booster vacuum threshold to determine if adequate brake booster vacuum is available to meet vehicle

5   braking requirements. If not, engine operation is modified to improve intake manifold vacuum such that brake booster vacuum requirements for vehicle braking are better satisfied.

[0011]   Many variations in the embodiments of present invention are contemplated, as described herein in more detail. Other applications of the

10   present invention will become apparent to those skilled in the art when the following description of the best mode contemplated for practicing the invention is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

15   [0012]   Figure 1 is a schematic representation of a motor vehicle brake system.

[0013]   Figure 2 is an overview flow chart of the brake booster vacuum prediction algorithm according to the present invention.

[0014]   Figures 3A and 3B depict a detailed flow chart according to a

20   first preferred embodiment of the brake booster vacuum prediction algorithm according to the present invention.

[0015]   Figures 4A and 4B depict a detailed flow chart of the brake booster vacuum prediction algorithm according to a second preferred embodiment of the present invention.

25   [0016]   Figures 5A and 5B depict a detailed flow chart of the brake booster vacuum prediction algorithm according to a third preferred embodiment of the present invention.

[0017]   Figures 6A and 6B depict a detailed flow chart according to a fourth preferred embodiment of the brake booster vacuum prediction

30   algorithm according to the present invention.

[0018] Figure 7 is a plot series of brake booster vacuum versus time for stop-and-go driving of a motor vehicle, including a measured brake booster vacuum, a first predicted brake booster vacuum using the method of Figures 3A and 3B, and, a second predicted brake booster vacuum using the

5 method of Figures 4A and 4B.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] Referring now to the Drawings, Figure 1 is a schematic representation of a motor vehicle brake system 100. The brake booster

10 vacuum prediction algorithm according to the present invention 102 resides, preferably, within the engine control module (ECM) 104. The ECM 104 controls the operation of the vehicle engine 106 and, through intake manifold vacuum 106V, the brake booster vacuum of the brake booster 112 providing brake pedal 116 assist to the master cylinder for actuation of the brakes

15 108a, 108b, 108c, 108d of the vehicle. External vehicle inputs 110 may be provided to the ECM 104 for purposes of operation of the present invention.

[0020] Figure 2 is an overview flow chart algorithm 200 of the brake booster vacuum prediction algorithm according to the present invention. The algorithm 200 starts at Block 202 through the main engine controller or

20 ECM then control passes to Block 204 where initialization of variables and parameters occurs. Brake booster vacuum is then predicted at Block 206 and compared at Block 208 to a predetermined calibrated brake booster vacuum threshold, available from the ECM. If brake booster vacuum is greater than the brake booster vacuum threshold (that is the absolute pressure of the brake

25 booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), denoting inadequate brake booster vacuum to meet vehicle braking requirements, then engine operation is modified at block 210 by the ECM to improve intake manifold vacuum to better meet brake booster vacuum requirements for vehicle braking, after which control passes to

30 Block 212. Otherwise, control passes to Block 212 without modifying

engine operation. Data for analyses is input, for example from the ECM, at Block 212 and is analyzed at Block 214 and saved in, preferably, ECM memory at Block 216, after which control passes back to Block 206, thereby enabling the algorithm to repeat. The main program of the ECM executes

5   Block 210 and, preferably, Block 208.

[0021]   Variables and parameters utilized in Figures 3A through 6B are in Table I, whereas, equations defining or utilizing the variables and parameters of Table I are incorporated within the appropriate functional blocks of Figures 3A through 6B.

10

Table I

Variable	Description
BF	Brake Flag (value can be either T=True or F=False)
BP	Brake Booster Pressure
BPROC	Brake Booster Pressure Rate of Change
LTIME	Loop Time (elapsed time between Brake Booster Vacuum predictions)
VDEC	Vehicle Deceleration
PATM	Barometric Pressure
BBV	Brake Booster Vacuum
DBP	Change in Brake Booster Pressure
DAT	Deceleration Apply Threshold
DRT	Deceleration Release Threshold
BIP	Brake Booster Inlet Pressure
MAP	Manifold Absolute Pressure
CVPL	Check Valve Pressure Loss
PVDEC	Previous Vehicle Deceleration
TAU	Brake Booster Vacuum Replenishment Time Constant

CF	Correction Factor
REFBP	Reference Brake Booster Pressure
XD	Brake Booster Diaphragm Displacement and Brake Master Cylinder Displacement

[0022] Figures 3A and 3B depict a detailed flow chart algorithm 300 of the brake booster vacuum prediction algorithm according to a first preferred embodiment of the present invention. The algorithm 300 starts at Block 302

5 through the main engine controller or ECM, then control passes to Block 304 where initialization of variables and parameters occurs. Brake booster pressure is then calculated at Block 306. If brake booster pressure is greater than atmospheric pressure at Block 308, brake booster pressure is set equal to atmospheric pressure at Block 310 and control passes to Block 312.

10 Otherwise, if brake booster pressure is not greater than atmospheric pressure at Block 308, control passes to Block 312. Brake booster vacuum is predicted at Block 312 by subtracting the brake booster pressure from atmospheric pressure and then compared at Block 314 to a predetermined calibrated brake booster vacuum threshold, available from the ECM. If brake booster vacuum

15 is greater than the brake booster vacuum threshold, (that is the absolute pressure of the brake booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), denoting inadequate brake booster vacuum to meet vehicle braking requirements, then engine operation is modified at block 316 by the ECM to provide adequate intake manifold

20 vacuum to meet brake booster vacuum requirements for vehicle braking. After which control passes to Block 318. Otherwise, control directly passes to Block 318 without modifying engine operation. The main program of the ECM executes Block 316 and, preferably, Block 314.

[0023] At Block 318, vehicle deceleration is assigned to the variable

25 PVDEC to be utilized as a previous deceleration, after which control passes to Block 319. At Block 319, vehicle deceleration is calculated from vehicle speed, available from the ECM, by linear regression or similar procedures well

know in the art. Control then passes to Block 320. If the brake flag is true at Block 320, then control passes to Block 322. Otherwise, control passes to Block 324.

[0024] At Block 322, if vehicle deceleration is greater than a

5 Deceleration Apply Threshold, or at Block 324, if vehicle deceleration is not less than a Deceleration Release Threshold, then control passes to Block 328. At Block 322, if vehicle deceleration is less than a Deceleration Apply Threshold, or at Block 324, if vehicle deceleration is less than a Deceleration Release Threshold, then control passes to Block 326. The Deceleration Apply

10 Threshold and Deceleration Release Threshold are predetermined parameters for a specific vehicle, stored in a lookup table, whose values are obtained either through previous calculations or empirically determined for a specific vehicle and compensated for parasitic losses, such as, for example, aerodynamic drag, rolling resistance, and powertrain drag.

15 **[0025]** For the case of control passing to Block 326, if the brake flag is true at Block 326, then a release brake event is determined as occurring and control passes to Block 330. The brake flag is set false at Block 330 and control passes to Block 332. At Block 326, if the brake flag is false, then a no brake event is determined as occurring and control passes to Block 334. The

20 change in brake booster pressure is equated to zero at Block 334 and control passes to Block 336. At Block 332, the change in brake booster pressure as a function of vehicle deceleration when a release brake event is determined as occurring is obtained from a Release Lookup Table, stored in memory, wherein values in the Release Lookup Table relating the change in brake

25 booster pressure as a function of vehicle deceleration have been empirically determined for the brake system for a specific vehicle. Control then passes from Block 332 to Block 336.

[0026] Brake booster pressure is calculated at Block 336 and brake booster inlet pressure is calculated at Block 338 wherein the MAP is available

30 from the ECM and the CVPL is a predetermined quantity, stored in memory, for each specific check valve. If brake booster pressure is greater than brake booster inlet pressure at Block 340, then control passes to Block 342, whereat

the rate of change of brake booster pressure is calculated. The brake booster vacuum replenishment time constant TAU utilized in Block 342 is empirically determined for a specific vehicle. For example, TAU is empirically determined to have a value from 0.25 seconds to 0.75 seconds depending upon

5   the brake system for a specific vehicle. Control then passes from Block 342 to Block 364, whereat variables are saved in, preferably, ECM memory after which control passes back to Block 306 enabling the process to repeat. If brake booster pressure is less than brake booster inlet pressure at Block 340, then the rate of change of brake booster pressure is equated to zero at Block

10   344 and control then passes to Block 364, whereat variables are saved in, preferably, ECM memory after which control passes to Block 306 enabling the process to repeat.

[0027]   For the case of control passing to Block 328, vehicle deceleration is calculated at Block 328, to be utilized as a present vehicle

15   deceleration incorporating compensation for parasitic losses, such as, for example, aerodynamic drag, rolling resistance, and powertrain drag, as previously mentioned. Control is then passed to Block 346. If the brake flag is true at Block 346, control passes to Block 348. Otherwise, an apply brake event is determined as occurring and control passes to Block 350. At Block

20   348, if vehicle deceleration is not greater than the previous vehicle deceleration, then a no brake event is determined as occurring and control passes to Block 352. At Block 352, the change in brake booster pressure is equated to zero, after which control passes to Block 336 and algorithmic execution continues as previously described. At Block 348, if vehicle

25   deceleration is greater than the previous vehicle deceleration, then an apply brake event is determined as occurring and control passes to Block 354.

[0028]   At Blocks 350 and 354, the change in brake booster pressure as a function of vehicle deceleration, when an apply brake event is determined as occurring, is obtained from an Apply Lookup Table, stored in memory,

30   wherein values in the Apply Lookup Table relating the change in brake booster pressure as a function of vehicle deceleration have been empirically determined for the brake system for a specific vehicle. Blocks 350 and 354

utilize the same Apply Lookup Table. Control passes from Block 350 to Block 356, whereas control passes from Block 354 to Block 358.

[0029] At Block 356, the present change in brake booster pressure is calculated utilizing, as one parameter, the change in brake booster pressure obtained in Block 350. The reference brake booster pressure and correction factor in Block 356 are empirically determined for the brake system of a specific vehicle and are stored in memory. Control passes from Block 356 to Block 360, whereat the change in brake booster pressure is stored in memory as the variable BPOLD and the brake flag is set to true, after which control passes to Block 336 and algorithmic execution continues as previously described.

[0030] At Block 358, the present change in brake booster pressure is calculated utilizing, as one parameter, the change in brake booster pressure obtained in Block 354. The reference brake booster pressure and correction factor in Block 358 are empirically determined for the brake system of a specific vehicle and are stored in memory. Control passes from Block 358 to Block 362, whereat the change in brake booster pressure is stored in memory as the variable BPOLD, after which control passes to Block 336 and algorithmic execution continues as previously described.

[0031] Figures 4A and 4B depict a detailed flow chart algorithm 400 of the brake booster vacuum prediction algorithm according to a second preferred embodiment of the present invention. Variables and parameters utilized in Figures 4A and 4B are described in Table 1, wherein equations defining or utilizing the variables and parameters are incorporated within the appropriate functional blocks of Figures 4A and 4B and will be described hereinbelow in more detail as necessary.

[0032] The algorithm 400 starts at Block 402 through the main engine controller or ECM, then control passes to Block 404 where initialization of variables and parameters occurs. Brake booster pressure is then calculated at Block 406. If brake booster pressure is greater than atmospheric pressure at Block 408, brake booster pressure is set equal to atmospheric pressure at Block 410 and control passes to Block 412. Otherwise, if brake booster

pressure is not greater than atmospheric pressure at Block 408, control passes to Block 412. Brake booster vacuum is predicted at Block 412 by subtracting the brake booster pressure from atmospheric pressure and then compared at Block 414 to a predetermined calibrated brake booster vacuum threshold,

5   available from the ECM. If brake booster vacuum is greater than the brake booster vacuum threshold, (that is, the absolute pressure of the brake booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), denoting inadequate brake booster vacuum to meet vehicle braking requirements, then engine operation is modified at block 416 by the ECM to

10   provide adequate intake manifold vacuum to meet brake booster vacuum requirements for vehicle braking. After which control passes to Block 418. Otherwise, control passes directly to Block 418 without modifying engine operation. The main program of the ECM executes Block 416 and, preferably, Block 414. At Block 418, vehicle deceleration is calculated from vehicle

15   speed, available from the ECM, by linear regression or similar procedures well know in the art. Control then passes to Block 420. If the brake flag is true at Block 420, then control passes to Block 422. Otherwise, control passes to Block 424.

[0033] .   At Block 422, if vehicle deceleration is greater than a

20   Deceleration Apply Threshold, or at Block 424, if vehicle deceleration is not less than a Deceleration Release Threshold, then control passes to Block 428. At Block 422, if vehicle deceleration is not greater than a Deceleration Apply Threshold, or at Block 424, if vehicle deceleration is less than a Deceleration Release Threshold, then control passes to Block 426. The Deceleration Apply

25   Threshold and Deceleration Release Threshold are predetermined parameters for a specific vehicle, stored in a lookup table, whose values are obtained either through previous calculations or empirically determined for a specific vehicle and compensate for parasitic losses, such as, for example, aerodynamic drag, rolling resistance, and powertrain drag.

30   **[0034]**   For the case of control passing to Block 426, the brake flag is set false at Block 426 and control passes to Block 430.

[0035] For the case of control passing to Block 428, vehicle deceleration is calculated at Block 428, to be utilized as a present vehicle deceleration incorporating compensation for parasitic losses, such as, for example, aerodynamic drag, rolling resistance, and powertrain drag as previously mentioned. Control is then passed to Block 442, whereat the brake flag is set true and control then passes to Block 430.

[0036] At Block 430, vehicle parameters are calculated, to be described later, and control then passes to Block 444. If the brake flag is true at Block 444, control passes to Block 432. Otherwise, a release brake event or a no brake event is determined as occurring and control passes to Block 446, whereat the brake booster pressure is calculated on brake release, to be described later, and control then passes to Block 432.

[0037] Brake booster inlet pressure is calculated at Block 432, wherein the MAP is available from the ECM and the CVPL is a predetermined quantity, stored in memory, for each specific check valve. If brake booster pressure is greater than brake booster inlet pressure at Block 434, then control passes to Block 436, whereat the rate of change of brake booster pressure is calculated. The brake booster vacuum replenishment time constant TAU utilized in Block 436 is empirically determined for a specific vehicle. For example, TAU is empirically determined to have a value from 0.25 seconds to 0.75 seconds depending upon the brake system for a specific vehicle. Control then passes from Block 436 to Block 440 whereat variables are saved in, preferably, ECM memory. Control then passes to Block 406 enabling the process to repeat. If brake booster pressure is less than brake booster inlet pressure at Block 434, then the rate of change of brake booster pressure is equated to zero at Block 438, and control then passes to Block 440, whereat variables are saved in, preferably, ECM memory after which control passes to Block 406 enabling the process to repeat.

[0038] Figures 5A and 5B depict a detailed flow chart algorithm 500 of the brake booster vacuum prediction algorithm according to a third preferred embodiment of the present invention. Variables and parameters utilized in Figures 5A and 5B are described in Table 1, wherein equations

defining or utilizing the variables and parameters are incorporated within the appropriate functional Blocks of Figures 5A and 5B and will be described herein below in more detail as necessary.

[0039] The algorithm 500 starts at Block 502 through the main engine controller or ECM, then control passes to Block 504 where initialization of variables and parameters occurs. Brake booster pressure is then calculated at Block 506. If brake booster pressure is greater than atmospheric pressure at Block 508, brake booster pressure is set equal to atmospheric pressure at Block 510 and control then passes to Block 512. Otherwise, if brake booster pressure is not greater than atmospheric pressure at Block 508, control passes to Block 512. Brake booster vacuum is predicted at Block 512 by subtracting the brake booster pressure from atmospheric pressure and then compared at Block 514 to a predetermined calibrated brake booster vacuum threshold, available from the ECM. If brake booster vacuum is greater than the brake booster vacuum threshold, (that is the absolute pressure of the brake booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), denoting inadequate brake booster vacuum to meet vehicle braking requirements, then engine operation is modified at block 516 by the ECM to provide adequate intake manifold vacuum to meet brake booster vacuum requirements for vehicle braking. After which control passes to Block 518. Otherwise, control passes directly to Block 518 without modifying engine operation.

[0040] The main program of the ECM executes Block 516 and, preferably, Block 514. At Block 518, brake booster diaphragm displacement or brake master cylinder displacement XD is determined from brake pedal position, as previously described, wherein master cylinder displacement is equal to brake booster diaphragm displacement. The brake booster diaphragm position as a function of the brake pedal position is, preferably, empirically determined and stored in memory. Control then passes to Block 520. If the brake booster diaphragm position is greater than zero at Block 520, then an applied brake event is determined as occurring and control passes to Block

522. Otherwise, a no brake event is determined as occurring and control passes to Block 524.

[0041] The brake flag is set true at Block 522 and control passes to Block 526. Otherwise, the brake flag is set false at Block 524 and control passes to Block 526. At Block 526, vehicle parameters are calculated, to be described later, and control then passes to Block 528. If the brake flag is true at Block 528, then control passes to Block 532. Otherwise, a no brake event is determined as occurring and control passes to Block 530, whereat the brake booster pressure is calculated on brake release, to be described later, and control then passes to Block 532.

[0042] Brake booster inlet pressure is calculated at Block 532, wherein the MAP is available from the ECM and the CVPL is a predetermined quantity, stored in memory, for each specific check valve. If brake booster pressure is greater than brake booster inlet pressure at Block 534, then control passes to Block 536, whereat the rate of change of brake booster pressure is calculated. The brake booster vacuum replenishment time constant TAU utilized in Block 536 is empirically determined for a specific vehicle. For example, TAU is empirically determined to have a value from 0.25 seconds to 0.75 seconds depending upon the brake system for a specific vehicle. Control then passes from Block 536 to Block 540, whereat variables are saved in, preferably, ECM memory after which control passes to Block 506 enabling the process to repeat. If brake booster pressure is less than brake booster inlet pressure at Block 534, then the rate of change of brake booster pressure is equated to zero at Block 538 and control then passes to Block 540, whereat variables are saved in, preferably, ECM memory after which control passes to Block 506 enabling the process to repeat.

[0043] In addition to the variables and parameters described in Table 1, Blocks 430 and 446 of Figure 4B and Blocks 526 and 530 of Figures 5A and 5B utilize parameters presented in Table II. All known or empirically determined values of variables or functions are stored in ECM memory and are available for calculations. Known variables are those whose values can be

determined, for example, by measurement, for example, the mass of the vehicle, area of the brake master cylinder, and booster diaphragm area.

Table II

Variable	Description	Determination
FDEC	Vehicle decelerating force	Calculated
M	Mass of vehicle	Known
BT	Total brake system torque	Calculated
RR	Rolling radius of wheel	Known
PL	Brake line pressure	Calculated
STT	Total specific torque	Empirically Determined
FO	Brake booster output force to brake master cylinder	Calculated
FI	Brake booster input force	Calculated
FB	Brake booster force	Calculated
GB	Brake booster gain	Empirically Determined
PA	Brake booster apply side pressure	Calculated
AD	Brake booster diaphragm area	Known
DF	Brake fluid displacement for a wheel	Calculated
VF	Total volume of brake fluid displaced (Sum of DF for all wheels)	Calculated
AMC	Brake master cylinder area	Known
VB	Total brake booster volume	Calculated
SB	Brake booster stroke	Known
VV	Brake booster vacuum side volume	Calculated
VA	Brake booster apply side volume	Calculated
MV	Mass of air in brake booster vacuum side volume	Calculated
MA	Mass of air in brake booster apply side volume	Calculated
R	Universal Gas Constant for air	Known
T	Temperature of air in Kelvin	Known
b, c and K	Brake constants specific to a wheel of the vehicle	Empirically Determined

5

[0044]   The following equations are utilized in Block 430 of Figure 4B and Block 526 of Figure 5A to calculate vehicle parameters:

$$FDEC = M*VDEC \tag{1}$$

$$BT = FDEC/RR \tag{2}$$

$$PL = BT/SST \tag{3}$$

$$FO = PL*AMC \tag{4}$$

$$FB = GB*FO/(1 + GB) \tag{5}$$

$$PA = BP + FB/AD \tag{6}$$

$$X = c*PL \text{ (variable used in equation 10)} \tag{7}$$

$$DF = (1 + e^{-X})*(K*PL + b) \tag{8}$$

$$XD = VF/AMC \tag{9}$$

$$VB = AD*SB \tag{10}$$

$$VV = VB - XD*AD \tag{11}$$

$$VA = XD*AD \tag{12}$$

$$MV = BP*VV/(R*T) \tag{13}$$

$$MA = PA*VA/(R*T) \tag{14}$$

[0045]   The following equations are utilized in Block 446 of Figure 4B and Block 530 of Figure 5B to calculate the brake booster pressure on brake release:

$$VA = 0 \tag{15}$$

$$VV = VB \tag{16}$$

$$MV = MV + MA \tag{17}$$

$$BP = MV*R*T/VV \tag{18}$$

MV and MA on the right hand side of equation (17) are defined by equations (13) and (14).

[0046]   Figures 6A and 6B depict a detailed flow chart algorithm 600 of the brake booster vacuum prediction algorithm according to a fourth preferred embodiment of the present invention. The algorithm 600 starts at Block 602 through the main engine controller or ECM then control passes to Block 604 where initialization of variables and parameters occurs. Brake booster pressure is then calculated at Block 606. If brake booster pressure is greater than atmospheric pressure at Block 608, brake booster pressure is set

equal to atmospheric pressure at Block 610 and control passes to Block 612. Otherwise, if brake booster pressure is not greater than atmospheric pressure at Block 608, control passes to Block 612. Brake booster vacuum is predicted at Block 612 by subtracting the brake booster pressure from atmospheric

5   pressure and then compared at Block 614 to a predetermined calibrated brake booster vacuum threshold, available from the ECM. If brake booster vacuum is greater than the brake booster vacuum threshold, (that is the absolute pressure of the brake booster vacuum is higher than the absolute pressure of the brake booster vacuum threshold), denoting inadequate brake booster

10 vacuum to meet vehicle braking requirements, then engine operation is modified at block 616 by the ECM to provide adequate intake manifold vacuum to meet brake booster vacuum requirements for vehicle braking. After which control passes to Block 618. Otherwise, control directly passes to Block 618 without modifying engine operation. The main program of the

15 ECM executes Block 616 and, preferably, Block 614.

[0047] At Block 618 brake booster diaphragm displacement or brake master cylinder displacement XD is assigned to the variable PXD to be utilized as a previous brake booster diaphragm displacement or brake master cylinder displacement after which control passes to Block 619. At Block 619,

20 brake booster diaphragm displacement or brake master cylinder displacement XD is determined from brake pedal position, as previously described, wherein master cylinder displacement is equal to brake booster diaphragm displacement. The brake booster diaphragm position as a function of the brake pedal position is, preferably, empirically determined and stored in

25 memory. Control then passes to Block 620. If XD is greater than zero at Block 620, control passes to Block 646. Otherwise, control passes to Block 626.

[0048] If the brake flag is true at Block 626, then a release brake event is determined as occurring, the brake flag is set false at Block 630 and control

30 passes to Block 632. If the brake flag is false at Block 626, then a no brake event is determined as occurring, the change in brake booster pressure is equated to zero at Block 634 and control passes to Block 636. At Block 632,

the change in brake booster pressure as a function of XD when a release brake event is occurring is obtained from a Release Lookup Table, stored in memory, wherein values in the Release Lookup Table relating the change in brake booster pressure as a function of XD have been empirically determined

5   for the brake system for a specific vehicle. Control then passes from Block 632 to Block 636.

[0049]   Brake booster pressure is calculated at Block 636 and brake booster inlet pressure is calculated at Block 638 wherein the MAP is available from the ECM and the CVPL is a predetermined quantity, stored in memory,

10   for each specific check valve. If brake booster pressure is greater than brake booster inlet pressure at Block 640, then control passes to Block 642, whereat the rate of change of brake booster pressure is calculated. The brake booster vacuum replenishment time constant TAU utilized in Block 642 is empirically determined for a specific vehicle. For example, TAU is empirically

15   determined to have a value from 0.25 seconds to 0.75 seconds depending upon the brake system for a specific vehicle. Control then passes from Block 642 to Block 664 whereat variables are saved in, preferably, ECM memory after which control passes to Block 606 enabling the process to repeat. If brake booster pressure is less than brake booster inlet pressure at Block 640, then the

20   rate of change of brake booster pressure is equated to zero at Block 644 and control then passes to Block 664, whereat variables are saved in, preferably, ECM memory after which control passes to Block 606 enabling the process to repeat.

[0050]   For the case of control passing to Block 646, if the brake flag is

25   true at Block 646 control passes to Block 648. Otherwise, an apply brake event is determined as occurring and control passes to Block 650. At Block 648, if XD is less'than the previous XD (i.e. PXD), a no brake event is determined as occurring and control passes to Block 652 whereat the change in brake booster pressure is equated to zero, after which control passes to

30   Block 636 and algorithmic execution continues as previously described. At Block 648, if XD is greater than the previous XD (i.e. PXD), an apply brake event is determined as occurring and control passes to Block 654.

[0051] At Blocks 650 and 654, the change in brake booster pressure as a function of XD, when an apply brake event is determined as occurring, is obtained from an Apply Lookup Table, stored in memory, wherein values in the Apply Lookup Table relating the change in brake booster pressure as a

5 function of XD have been empirically determined for the brake system for a specific vehicle. Blocks 650 and 654 utilize the same Apply Lookup Table. Control passes from Block 650 to Block 656, whereas control passes from Block 654 to Block 658.

[0052] At Block 656, the present change in brake booster pressure is

10 calculated utilizing, as one parameter, the change in brake booster pressure obtained in Block 650. The reference brake booster pressure and correction factor in Block 656 are empirically determined for the brake system of a specific vehicle and are stored in memory. Control passes from Block 656 to Block 660, whereat the change in brake booster pressure is stored in memory

15 as the variable BPOLD and the brake flag is set to true, after which control passes to Block 636 and algorithmic execution continues as previously described.

[0053] At Block 658, the present change in brake booster pressure is calculated utilizing, as one parameter, the change in brake booster pressure

20 obtained in Block 654. The reference brake booster pressure and correction factor in Block 658 are empirically determined for the brake system of a specific vehicle and are stored in memory. Control passes from Block 658 to Block 662, whereat the change in brake booster pressure is stored in memory as the variable BPOLD, after which control passes to Block 636 and

25 algorithmic execution continues as previously described.

[0054] Figure 7 depicts a series of plots 700 which illustrate the foregoing exposition. A motor vehicle under stop-and-go conditions was used, wherein brake booster vacuum, indicated by absolute pressure, is plotted as a function of driving time. Plot 702 indicates actual measured brake

30 booster vacuum. Plot 704 indicates predicted brake booster vacuum determined by the method of Figures 3A and 3B. Finally, Plot 706 indicates predicted brake booster vacuum determined by the method of Figures 4A and

4B. As can be readily seen, both prediction modalities (Figures 3A, 3B and Figures 4A, 4B) provide brake booster vacuum values which correlate well to the measured values.

[0055] To those skilled in the art to which this invention appertains, the above described preferred embodiment may be subject to change or modification. Such change or modification can be carried out without departing from the scope of the invention, which is intended to be limited only by the scope of the appended claims.